

METHOD FOR DEPOSITING SILICON OXIDE  
INCORPORATING AN OUTGASSING STEP

Field of the Invention

001       The present invention generally relates to a method for depositing an inter-metal-dielectric (IMD) layer on a semiconductor substrate and more particularly, relates to a method for depositing a silicon oxide dielectric layer on a silicon wafer by plasma enhanced chemical vapor deposition incorporating a heat-treating step for outgassing prior to the deposition process.

Background of the Invention

002       In the processing of semiconductor wafers into IC devices, a multiplicity of fabrication steps, i.e., as many as several hundred, are usually required to complete the fabrication of an IC circuit. For instance, various steps of deposition, cleaning, ion implantation, etching and passivation must be completed before an IC chip can be tested and packaged for shipment.

003       One of the most frequently required processes in the fabrication of IC circuits is the oxide deposition process.

Silicon dioxide films can be deposited by a chemical vapor deposition (CVD) method at a reaction temperature as low as 400°C without consuming silicon in the substrate. The deposition temperature can be further reduced by a plasma-enhanced CVD method. The deposition and the sometimes necessary annealing conditions depend on the application of the oxide layer. When the oxide layer is used as an insulator between conductive layers, the oxide film can be deposited undoped and then densified at elevated temperatures. A common method for depositing silicon dioxide films is the oxidation of silane with oxygen at low pressure and low temperature (such as 400~450°C). The reaction of silane with nitrous oxide ( $\text{NO}_2$ ) can also be used to produce stoichiometric silicon dioxide or silicon-rich oxide by varying the  $\text{NO}_2/\text{SiH}_4$  ratio.

004 In the  $\text{SiO}_2$  fabrication process, it is desirable to use the plasma-enhanced CVD method such that the substrate can be kept at a low temperature, for instance, at a temperature of 300°C or lower. This is achieved by reacting gases in a glow discharge to produce a plasma which then supplies much of the energy needed for the reaction. A plasma can generally be created by applying a high electric field at a frequency of typically 13.5 MHZ in the gas mixture. A plasma thus produced contains high energy electrons,

gas molecules, fragments of gas molecules and free radicals. A plasma-enhanced CVD oxide film can be formed by the reaction of silane at a reaction temperature of approximately 350°C with N<sub>2</sub>O in a glow discharge. The oxide film produced by a silane and nitrous oxide gas mixture tends to have better uniformity than the oxide film formed by an oxygen reactant gas. In a typical silane/nitrous oxide reaction, silicon dioxide, nitrogen and hydrogen are produced as the end products.

005 Prior to the deposition of an oxide film on a wafer surface, it is desirable that the wafer surface be cleaned or treated by a physical or chemical method. For instance, a recently developed technique of plasma assisted cleaning which utilizes plasma energy to create reactive species for cleaning or treatment of a wafer surface. In the plasma cleaning process, the wafer is normally placed remote from the plasma in order to avoid radiation damage to the wafer itself. The chemically reactive species are then removed from the plasma region and supplied to the wafer in the form of an afterglow gas. This type of remote plasma technique, for instance, has been used to create chemical reactions in the gas phase for the removal of organic materials from the surface of a wafer with oxygen, i.e., by a nitrous oxide plasma.

A plasma assisted chemical cleaning (or etching) is used when isotropic etching is required or when dimensional control is not critical. One of the common plasma assisted chemical etching methods is the removal of photoresist by an oxygen plasma, sometimes referred to as a plasma ashing process wherein oxygen atoms or ions react with organic materials to form volatile products such as CO, CO<sub>2</sub> and H<sub>2</sub>O. A barrel reactor can be used for the plasma ashing process.

006 In a conventional process of oxide deposition by the PECVD method, a N<sub>2</sub>O plasma treatment is first performed on the wafer surface to remove all contaminants and impurities. The conventional treatment process can be carried out by first providing a stable vacuum in the process chamber and then by the plasma treatment step. The process chamber is then stabilized with stable reactants before the start of a deposition process.

007 The oxygen plasma treatment process when followed by a PECVD oxide deposition process, creates other processing problems. For instance, when an oxide deposition process proceeds immediately after the N<sub>2</sub>O plasma treatment process, residual gases left in the reaction chamber such as moisture, N<sub>2</sub>O, O<sub>2</sub>, oxygen ions and

photoresist residue can cause problems in the deposition process. The residual gases can be absorbed by the silicon wafer, i.e., at least by a surface layer of the wafer and then driven out of the wafer during a subsequent plasma deposition process conducted at a high deposition temperature such as at about 400°C. The impurity gases, particularly the moisture or water vapor that is absorbed in the silicon surface, cause the most problem since some of the moisture does not have time to escape from the silicon surface and is thus covered by the deposited oxide film leading to void problems. The void problem, or sometimes known as "the bubbling problem," is more severe at the wafer edge where it is more likely for silicon to absorb moisture and to cause cracking in the oxide layer that is subsequently deposited. The cracking or peeling of the oxide layer in turn causes severe quality problems in the subsequently deposited and formed metal interconnect lines, i.e., possible shorting in the metal interconnect lines. The outgassing of the impurity gases, including that of water vapor, during the silicon oxide plasma deposition process must therefore be minimized or eliminated altogether to ensure reliability of the device fabricated and the yield of the fabrication process.

008        It is therefore an object of the present invention to provide a method for depositing an inter-metal-dielectric layer on a semiconductor wafer that does not have the shortcomings or drawbacks of the conventional deposition process for the IMD layers.

009        It is another object of the present invention to provide a method for depositing an IMD layer on a semiconductor wafer that does not have cracking or peeling problems of the IMD layer deposited.

0010      It is a further object of the present invention to provide a method for depositing an IMD layer on a semiconductor wafer by incorporating a heat-treating step into the deposition process.

0011      It is another further object of the present invention to provide a method for depositing an IMD layer of silicon oxide on a semiconductor wafer by first conducting an outgassing process during heat treatment to drive out impurity gases absorbed in the wafer surface prior to the deposition process.

0012 It is still another object of the present invention to provide a method for depositing a silicon oxide IMD layer on a semiconductor wafer by heat-treating the wafer at a temperature of at least 300°C for a length of time sufficient to outgas the wafer surface prior to the deposition process.

0013 It is yet another object of the present invention to provide a method for depositing a silicon oxide IMD layer on a semiconductor wafer by a plasma CVD technique wherein the wafer is first heat-treated at a temperature of at least 350°C for at least 1 min. to evaporate impurity gases from the wafer surface prior to deposition.

0014 It is still another further object of the present invention to provide a method for depositing an oxide layer on a silicon wafer incorporating the step of heat-treating the silicon wafer at a temperature of at least 350°C for a length of time sufficient to outgas the wafer and then depositing a silicon oxide layer on the wafer by a plasma enhanced chemical vapor deposition technique.

Summary of the Invention

0015        In accordance with the present invention, a method for depositing a silicon oxide inter-metal-dielectric layer on a semiconductor wafer incorporating a heat treatment step for outgassing the wafer surface prior to the deposition process is provided.

TOP SECRET//  
COMINT//  
SIGNAL//  
NSA/CSS//  
NOFORN//  
REF ID: A6160

0016        In a preferred embodiment, a method for depositing an inter-metal-dielectric layer on a semiconductor substrate by plasma chemical vapor deposition can be carried out by the operating steps of first providing a pre-processed semiconductor substrate; positioning the semiconductor substrate in a plasma CVD chamber; heating the semiconductor substrate in the chamber to a temperature of at least 300°C for a length of time sufficient to outgas a surface of the semiconductor substrate; and conducting a plasma CVD process on the semiconductor substrate and depositing the inter-metal-dielectric layer.

0017        In the method for depositing an inter-metal-dielectric layer on a semiconductor substrate, the semiconductor substrate is preferably heated to a temperature of at least 350°C during the heating step. The semiconductor substrate may be heated to a

temperature of at least 300°C for a time period of at least 30 sec., or preferably to a temperature of at least 350°C for a time period of at least 1 min. The method prevents the deposited inter-metal-dielectric layer from cracking due to outgassing from the semiconductor substrate. The inter-metal-dielectric layer deposited may be silicon oxide. The method may further include the step of flowing a precursor gas of silane into the plasma CVD chamber for depositing said IMD layer, or the step of flowing precursor gases of silane and nitrous oxide into the plasma CVD chamber for depositing the IMD layer. The semiconductor substrate may be heated to a temperature of 400°C for 1 min. during the heating step. The heating step and the depositing step are conducted in the same plasma CVD chamber.

0018        The present invention is further directed to a method for depositing an oxide layer on a semiconductor wafer which can be carried out by the operating steps of first positioning a pre-processed semiconductor wafer in a plasma process chamber; heat-treating the semiconductor wafer at a temperature of at least 350°C for a length of time sufficient to outgas the wafer; and depositing a silicon oxide layer on the wafer by a plasma enhanced chemical vapor deposition technique.

0019        The method for depositing an oxide layer on a semiconductor wafer may further include the step of positioning a pre-processed silicon wafer in the plasma process chamber. The method may further include the step of heat-treating the semiconductor wafer at a temperature of at least 350°C for a time period of at least 30 sec., or the step of heat-treating the semiconductor wafer at 400°C for 1 min. The method may further include the step of evacuating the plasma process chamber prior to the deposition step to a pressure of not higher than  $10^{-2}$  Torr, or the step of cleaning a surface of the semiconductor wafer by a nitrous oxide ( $N_2O$ ) plasma. The method may further include the step of flowing a precursor gas of silane into the plasma process chamber to carry out the deposition process, or the step of flowing precursor gases of silane and nitrous oxide into the plasma process chamber to carry out the deposition process. The method may further include the step of depositing the silicon oxide layer as an inter-metal-dielectric layer, or the step of outgassing moisture from the semiconductor wafer during the heat-treating step.

Brief Description of the Drawings

0020 These and other objects, features and advantages of the present invention will become apparent from the following detailed description and the appended drawings in which:

0021 Figure 1 is a graph illustrating the temperature/time relationship for a present invention plasma deposition process incorporating the heat-treating step.

0022 Figure 2 is a graph illustrating the fabrication yield on wafers processed prior to and after the implementation of the present invention method.

0023 Figure 3 is a graph illustrating daily defect count on wafers fabricated prior to and after the implementation of the present invention method.

0024 Figure 4 is a chart illustrating the percentage yield on three different lots of wafers produced with and without the present invention heat-treating step.

Detailed Description of the Preferred Embodiment

0025        The present invention discloses a method for depositing an inter-metal-dielectric layer on a semiconductor substrate by plasma chemical vapor deposition incorporating the additional step of heat-treating for outgassing impurity gases from the wafer surface prior to the deposition step such that cracking of the IMD layer deposited can be minimized or eliminated.

0026        In the method, a silicon substrate is first heat-treated in the plasma CVD chamber by plasma energy to a temperature of at least 300°C for a time period sufficient to outgas the surface of the semiconductor wafer prior to the deposition process. The semiconductor substrate is preferably treated at a temperature of at least 350°C for a time period of at least 30 sec. In a preferred embodiment, the silicon wafer is heat-treated at a temperature of 400°C for a time period of 60 sec. The heat treatment step can be carried out in-situ in the plasma process chamber by the plasma energy. The silicon wafer may also be treated in a separate chamber and then immediately transported into the plasma process chamber for the deposition process without exposing the wafer to a source of impurities or moisture.

0027        The present invention deposition process for forming the IMD layer can be carried out, after the heat treatment step, by flowing a precursor gas of silane, or precursor gases of silane and nitrous oxide into the plasma process chamber for the deposition process. The chamber pressure is normally kept at lower than  $10^{-2}$  Torr. The process may be carried out at a chamber temperature of about 400°C.

0028        The present invention novel method for treating a dielectric film to suppress high-density plasma (HDP) oxide defect can be carried out before the deposition process of the dielectric film in the plasma process chamber. The high-density plasma CVD method, with its excellent gap filling capability, has largely replaced sub-atmospheric pressure CVD for depositing inter-metal-dielectric layers as the semiconductor fabrication process continuously shrinking to deep-sub-micron levels. The present invention novel method minimizes or eliminates the as-deposited film cracking problem, particularly severe at the wafer edge, which may lead to device defects such as a short between interconnect metal lines.

0029        The present invention novel high-density plasma (HDP) treatment method can be used to heat wafers to a temperature of up to 400°C to outgas the wafer surface in the HDP chamber prior to the deposition process, such that wafer edge void formation (or bubbling) and cracking can be eliminated. The fabrication yield of the HDP process can be improved by more than 10% when the present invention pre-treatment method is used, for instance, by eliminating shorts between the interconnect lines. The heat treatment process can be advantageously conducted at a temperature between about 300°C and about 400°C.

0030        The invention provides a solution to HDP-IMD bubble defects which can otherwise lead to film peeling and contamination on the wafers. An average yield improvement can be realized from about 80% to about 91% with a minimal reduction in the wafer production rate. It has been found that the void defect or the bubbling defect occurs more frequently at wafer edge since the wafer edge is more susceptible of exposure to impurity gases, e.g., moisture.

0031        Referring to Figure 1, wherein a temperature/time plot of the present invention plasma deposition method incorporating a heat

treatment step is shown. It is seen that the initial curve, denoted by A, represents the pre-treatment step at a temperature of about 350°C for a time period of about 50 sec. after a wafer is first positioned in the plasma process chamber and the plasma is turned on without turning on the reactant gas flow. The plasma, which is ignited by the argon gas, bombards the wafer surface and causes it to be heated to a desired temperature which is controlled by the power supply to the plasma source. For instance, the radio frequency (RF) power supply to the plasma source may be in the range between about 1,000 W and about 3,000 W with the bias power switched off during the heat treatment process prior to deposition. After the heat treatment process is conducted for at least 30 sec., and preferably for at least 60 sec., the reactant gas flow, such as a flow of silane and nitrous oxide, is turned on to allow the reactant gases to enter into the process chamber and to carry out the deposition process. This is shown by curve B in Figure 1. The temporary dip in temperature between curve A and curve B is caused by the sudden flow of reactant gases into the chamber and the absorption of heat in the chamber by the reactant gas before the chamber resumes its set temperature. After the deposition process is completed, i.e., after about 480 sec., the chamber temperature is ramped down as shown in Figure 1 by curve C.

0032 It should be noted that a minimum of 30 sec. is required for the present invention heat treatment process when conducted at a temperature of about 350°C. The word "about" used in this writing indicates a range of values that is  $\pm$  10% of the average value given. It was discovered that in some experiments wherein the wafer is pretreated for only 20 sec., the bubbling or void defect does not disappear indicating that the outgassing process from the wafer surface is incomplete. It is therefore determined that a suitable length of time for the heat treatment is between about 30 sec. and about 60 sec. While a heat treatment time of longer than 60 sec. may also be possible, such longer length of time may not be necessary and would reduce the fabrication yield by increasing the cycle time.

0033 The fabrication yields on three lots of wafers, each containing twelve wafers, fabricated by the conventional process (as indicated by W01~W12), and by the present invention novel process (as indicated by W13~W25) are shown in Figure 2. It is seen that at least a 11% improvement in yield has been realized by utilizing the present invention HDP CVD method for depositing the IMD layer incorporating the heat treatment step. Data is also shown in Figure 4 indicating that not only the average yield is

improved by at least 11%, but also the reliability of the process is improved by achieving a lower standard deviation in the fabrication process, a decrease between of 3 and 5 fold. The present invention novel method therefore not only provides higher fabrication yield, but also produces products of higher reliability and consistency. Also shown in Figure 4 for comparison is data obtained by the conventional method of heating for a time period of 5 sec. The standard 5 sec. heating process is the time normally required to ramp up the chamber temperature to the deposition temperature.

0034 The desirability and effectiveness of the present invention novel method for depositing IMD layers by a HDP CVD method incorporating the pre-heating step is further shown in Figure 3. Figure 3 is a plot of the daily defect count on wafers fabricated prior to and after the implementation of the present invention novel heat treatment method. The implementation of the present invention method is on 2/13 at near the end of the curve. It is seen that the defect count is significantly reduced after 2/13 from about 50 to about 20. An improvement of at least 60% in defect count is thus realized by utilizing the present invention

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novel deposition method incorporating the heat treatment step for outgassing the impurity gases.

0035       The present invention novel method for depositing an inter-metal-dielectric layer on a semiconductor wafer by plasma chemical vapor deposition incorporating a heat treatment step prior to deposition has therefore been amply described in the above description and in the appended drawings of Figures 1-4.

0036       Furthermore, while the present invention has been described in terms of a preferred embodiment, it is to be appreciated that those skilled in the art will readily apply these teachings to other possible variations of the inventions.

0037       The embodiment of the invention in which an exclusive property or privilege is claimed are defined as follows.